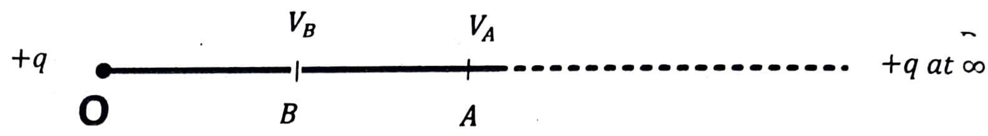
If someone tell you that electric potential at a point is 10 Volt, what this mean?
Answer: this means that; 10J of work has been done in bringing a unit positive charge from infinity to that point along any path.
Or we can also say that potential energy of a body at that point is 10J.

Electric potential difference



⇒ Consider a point charge +q placed at point O in space, then points A and B are in electric field of charge +q.

$$Electric\ potential\ at\ A, V_A = \frac{W_{\infty A}}{q_o} = \frac{U_A}{q_o}$$

$$Electric\ potential\ at\ B, V_B = \frac{W_{\infty B}}{q_o} = \frac{U_B}{q_o}$$

$$V_B - V_A = \frac{W_{\infty B}}{q_o} - \frac{W_{\infty A}}{q_o} = \frac{W_{\infty B} - W_{\infty A}}{q_o} = \frac{W_{AB}}{q_o}$$

⇒ $V_B - V_A = work\ done/Coulomb$ in moving a $+q_o$ from A to B.

⇒ $clearly\ V_B > V_A$ i.e.... potential at B is at higher potential than point A.

⇒ So, it can be defined as; "electric potential difference is between two points in an electric field is the amount of work done in bringing a unit positive from the point of lower potential (point A) to the point of higher potential (point A).

⇒ ***Si unit of electric potential difference:***
As Si unit of electric potential is Volt, so the same unit is also used for electric potential difference.
Thus, potential difference between any points will be 1V if 1 joule of work is done in bringing a unit positive charge from the point of lower potential to the point of higher potential.

Why the work done in bringing $+q_o$ from 1 point to other point is independent of path?
Answer: it is because like gravitational force, electrostatic force is also conservative in nature. This shows that "work done in moving a unit positive charge over a closed path in an electrostatic field is zero".
So, this is the reason behind that.

Electric potential due to a single point charge:

⇒ The electric potential due to a single point charge is given by;

$$V = k\frac{q}{r}$$

$$V_{single\ point} = \frac{q}{4\pi\epsilon_o r}$$

⇒ If q is positive then potential at that point will be positive.

⇒ If q is negative then potential at that point will be negative.

⇒ $V_{single\ point} = 9 \times 10^9 \frac{q}{r}$ ... $in\ free\ space\ or\ air$

⇒ $V_{single\ point} = 9 \times 10^9 \frac{q}{Kr}$ ...$in\ a\ medium$

⇒ At $r = \infty$ in free space or air $9 \times 10^9 \frac{q}{\infty}$, so electric potential is zero at infinity.

⇒ At equal distance from the point charge $+q$, V is the same, therefore V due to a single point charge has a spherical symmetry.

⇒ For a point charge $v \propto \frac{1}{r}$ $and\ E \propto \frac{1}{r^2}$ therefore due to a point charge +q, the electric field intensity E decreases more rapidly that the potential V with increasing distance r.

Important point:
The potential near an isolated positive charge is positive because work is done by external agency to push a test

charge (positive) from infinity to that point.
The potential near an isolated negative charge is negative because outside agent must exert a restraining force as test charge come in from infinity.

Electric potential energy of TWO charge system:

⇒ For this first we will assume that the two charges $+q_1$ and $+q_2$ are infinite apart at rest.

⇒ Equation is given by;

$$W = \frac{q_1 q_2}{4\pi\epsilon_o r_{12}}$$

r_{12} *is the distaance between* q_1 *and* q_2

⇒ If the two charges are of the same sign, the potential energy of the system is positive.

⇒ If the two charges are of opposite sign then potential energy in this case will be negative.

⇒ Note that potential energy of a charge is independent of the order of assembly of charges.

⇒ Positive potential energy means that work can be obtained from the system.

⇒ Negative potential energy means that external agent would have to do work to separate the charges.

⇒ The potential energy of like charges increases as they are brought nearer and decreases as they move apart.

⇒ Reverse in the case for unlike charges.

When point charges are infinite distance apart the electric potential energy of such a system is zero, why?
Answer: It is because their field do not interact each other.
What will happen if these charges are brought from infinity to their respective positions?
Answer: external work shall have to be done to do so.

Potential energy of a single charge in external electric field:

⇒ Work done in bringing a charge q from infinity to point p is;

$$W = qV$$

This work done is stored in the charged particle in the form of potential energy.
If $\vec{r}$ is the position vector of point P relative to some origin then,

$$P.E \text{ of } q \text{ at } \vec{r} \text{ in external field is;}$$

$$U(\vec{r}) = qV(\vec{r})$$

Potential Gradient

⇒ Gradient is term used for change with respect to displacement.

$$\frac{\Delta}{\Delta r}$$

⇒ So, it can be defined as, "the change with respect to displacement is knows as potential gradient".

⇒ Or simply it can be defined as 'electric field intensity is equal to the negative gradient of potential'.

⇒ ***Mathematically it can be represented by;***

$$E = \frac{-\Delta V}{\Delta r}$$

⇒ The negative sign shows that the direction of $\vec{E}$ is in the direction of decreasing potential.

⇒ ***Equality of unit with previous unit of E:***

The electric field intensity ($= -\frac{\Delta V}{\Delta r}$) can also be expressed in volt/meter (V/m). The reader may recall that previously the unit N/C was assigned to E. in fact these two units are same.

Some important interpretations

$if\ \Delta V = +ve, V\ is\ increasing$	*in this case E will be negative*
$if\ \Delta V = -ve, V\ is\ decreasing$	*in this case E will be positive*

Difference between Electric potential energy and electric potential:

Electric Potential energy	*Electric potential*
It can be defined as total work done on total charge.	It can be defined as work done on a unit charge.
It is the total potential energy of a total charge.	It is the potential energy possessed by a unit charge.

We will often use two words consecutively;

i. Positive plate
ii. Negative plate

i. ***Positive plate:***
- ✓ High potential with respect to positive test charge.
- ✓ Zero potential with respect to negative test charge.

ii. ***Negative plate:***
- ✓ High potential with respect to negative test charge.
- ✓ Zero potential with respect to positive test charge.

Electron volt:

⇒ The conventional unit of energy is joule but this is very large, that's why we cannot use it on atomic level.
⇒ So, on atomic level we use another unit of energy called electron volt (abbreviated as ev).
⇒ 1 ev is the amount of energy gained by an electron when accelerated through a potential difference of $1V$.
⇒ The energy gained by a charge q through a potential difference of V volts = qV

$$1eV = 1.6 \times 10^{-19} \times 1 = 1.6 \times 10^{-19} J \ (here\ q = 1.6 \times 10^{-19}C\ and\ V = 1Volts)$$

$$1eV = 1.6 \times 10^{-19}C$$

⇒ It is not a standard unit, we should convert our result to an Si unit of energy (joule) after finishing our problem.
⇒ Energy acquired by a charged particle in eV when it is accelerated by V volt is E = (charge in quanta) × (p.d. in volt)

S-N	Charge	Accelerated by p.d	Gain in K.E
1.	Proton	$5 \times 10^4 V$	$K.E = e \times 5 \times 10^4 V = 5 \times 10^4\ eV = 8 \times 10^{-15} J$
2.	Electron	$100\ V$	$K.E = e \times 100V = 100eV = 1.6 \times 10^{-17} J$
3.	Proton	$1V$	$K.E = e \times 1V = 1eV = 1.6 \times 10^{-19} J$
4.	$0.5C$	$2000V$	$K.E = 0.5 \times 2000 = 1000J$
5.	$\alpha - particle$	$10^6\ V$	$K.E = (2e) \times 10^6 V = 2MeV$

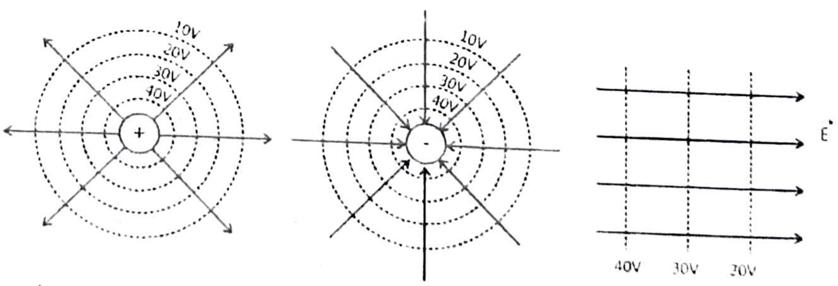
Equipotential surfaces:

EQUI = SAME

⇒ Equipotential surface is any surface through which electric potential is same at every point.
⇒ Or the potential difference between any two points of equipotential surface is zero.
⇒ It may be noted that equipotential surface may be surface of a material body or a surface in a space.

Properties:

⇒ The equipotential surfaces produced by a point charge or a spherically charge distribution are a family of concentric spheres.

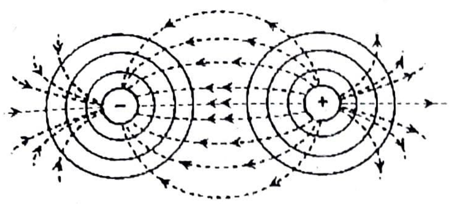


⇒ No work is done in moving a test charge over an equipotential surface:

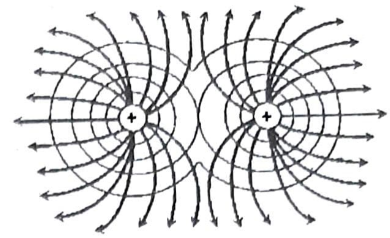
$$so\ W = 0$$

⇒ Electric field is always normal to the equipotential surface at any point.
⇒ The space between equipotential surfaces enable us to identify region of strong and week fields.
⇒ They never intersect each other.
⇒ A metallic surface of any shape is an equipotential surface e.g. When a charge is given to a metallic surface, it distributes itself in a manner such that its every point comes at same potential even if the object is of irregular shape and has sharp points on it.

⇒ Equipotential surface for pair of charges.



Pair of two equal and opposite charges



Pair of two equal and similar charges

Similarities between equipotential and electric field lines:

✓ Both represents electric field.

✓ Both tells us that what would happen to the charge in electric field.

Difference between equipotential and electric field lines:

Equipotential line	*Electric field lines*
Equipotential line gives us clear picture about electric field at various points.	The field lines tell little about the strength of field.
The equipotential surfaces tell the direction of electric field. Now $E = -\Delta V/\Delta r$ tells that $\vec{E}$ points in the direction of decreasing potential.	Electric field lines give no such idea.

$$1\,V/m = \frac{joule/coulomb}{metre} = \frac{newton \times metre}{coulomb \times metre} = 1\,N/C$$

Misconception:

Incorrect: Where electric field is zero, electric potential is also zero.

Correct: It is not always correct, for example in a charged conducting shell, electric field inside the shell E = 0 but potential is not zero.

Incorrect: Where electric potential is zero, electric field is also zero.

Correct : It is not always correct. In the case of equatorial plane of an electric dipole the electric potential is zero but the electric field is non-zero.

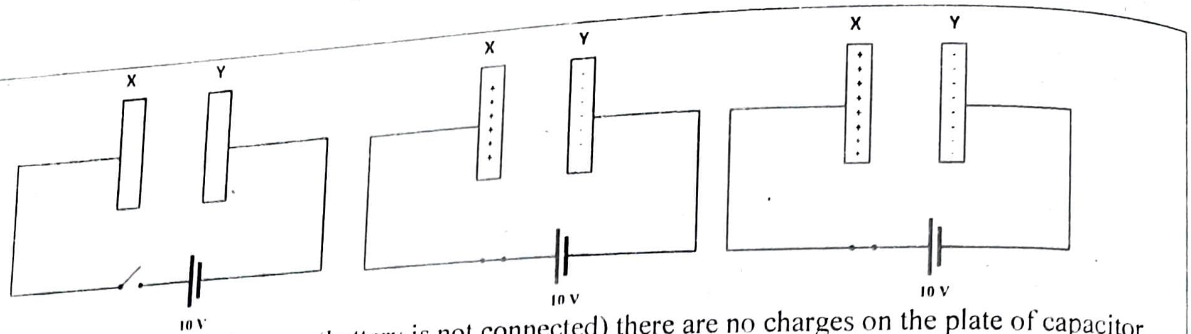
Capacitor

- Capacitor is a device used for storing charge.
- It actually stores electrical energy in small space.
- ***Construction:***
  It consists of two conducting surfaces (generally called plates) separated by insulating material called dielectric.
  The most common dielectrics are air, mica, paper etc.
- ***Capacitance:***
  The ability of capacitor to store charge is called its capacitance.

$$Capacitance \propto ability\ of\ storing\ electrical\ energy$$

- They play important function in both AC and DC.
- ***Naming of capacitor:***
  A capacitor is generally named after the dielectric used, like air capacitor, mica capacitor, paper capacitor etc.
- Capacitor may be parallel plate, concentric cylinders etc.

It is important to know, How capacitor store electrical energy? (Concept)
Answer: given diagram shows that how parallel capacitor stores electrical energy when connected to d.c source.



Case 1st: Initially when switch is open (battery is not connected) there are no charges on the plate of capacitor (plates of capacitor are neutral).
Case 2nd: In 2nd diagram when switch is closed (a 10 V battery is connected) the electrons from plate X will be attracted by the battery and these electrons starts accumulating on plate Y. this state is called charging of capacitor.
After a short time, the potential difference between plate X and plate Y becomes equal to 10 V, but is oppositely directed.
Case 3rd: in the third diagram capacitor is fully charged and the charging current ceases to flow.
At start the capacitor plates were neutral, now after a while it fully charged. This is the mechanism between charging of capacitor.

Some important points:

- The charging current will flow until the capacitor is fully charged.
- Once a capacitor fully charged then charging current ceases, so a charged capacitor prevents flow of direct current.
- The charging current does not flow through the capacitor, between the plates.
- There occurs only transfer of electron from one plate to other one.
- When capacitor fully charged the plates carry equal but opposite charge.
- The charge on capacitor means charge on either plate.
- There are equal loss and gain of electrons.
- The energy required to charge a capacitor or to make possible flow of electron from one plate to another is supplied by battery.

Capacitance:

⇒ It is the capacity of capacitor to store charge.
⇒ Experimentally it is proved that;

$$\text{Charge } (q) \text{stored on plate of capacitor} \propto \text{potential difference } (V)$$

$$q \propto V \Rightarrow \frac{q}{V} = constant = C$$

⇒ The constant of proportionality C is called capacitance.
⇒ It may be defined as, 'the ratio of charge on plates of capacitor to the potential difference across the plates of capacitor is called ***capacitance.***
⇒ ***It can also be defined as;***

$$C = \frac{q}{V}, if\ V = 1\ then\ C = q$$

it is the amount of charge required to raise its potential by unity.

⇒ ***Capacitance of capacitor depends upon:***

- ✓ Shape of its plates
- ✓ Separation between plates
- ✓ Nature of dielectric (insulating material) between the plates

⇒ ***Units:***

As $C = \frac{q}{V}$

$$if\ q = 1\ C, V = 1\ volt\ then\ C = \frac{q}{V} = \frac{1}{1} = 1\ farad$$

CALCULATING CAPACITANCE

To calculate the capacitance of a capacitor once we know its geometry: -
(a) Assume a charges q and −q on the plates;

(b) Calculate the electric field $\vec{E}$ between the plates in terms of this charge, using Gauss' law:
(c) Knowing $\vec{E}$, calculate the potential difference $\vec{V}$ between the plates.
(d) Calculate C.

A capacitor has a capacitance of 1 farad, what this mean?

Answer: it means that if a charge of 1 Coulomb accumulates on each plate when a p.d of 1V is applied across the plates.

Interesting points about farad:

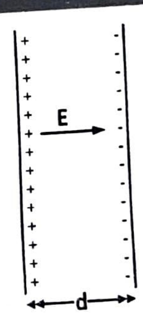
- ✓ Farad is extremely large unit of capacitance.
- ✓ Practically capacitor have capacitance in order of micro-farad, pico-farad etc....

$$1\mu F = 10^{-6}F, 1\,pF = 10^{-12}F$$

Some other important points about capacitance;

- ✓ The capacitance $C = \frac{q}{V}$ of a given capacitor is a constant quantity.
- ✓ If potential difference is doubled charge also becomes twice (2q) so that $(\frac{2q}{2V}) = \frac{q}{v}$ so C is constant.
- ✓ The greater the capacitance the greater is the ability of a capacitor to store charge for a given potential difference across it.
- ✓ Note that value of q *and* V do not occur in the expression of capacitance. This again reminds us that capacitance is a property of physical construction of capacitor.
- ✓ Capacitance of earth is quite large, we choose earth as a level of zero potential for practical purposes.

Capacitance of a parallel plate Air Capacitor:



⇒ A parallel plate capacitor consists of two flat, parallel metal plates separated by small distance. (as shown in figure.

⇒ The space between the two plates may have air, vacuum which have the same properties.

⇒ There may be insulating materials between the plates such as, mica, glass or paper.

Let; A = area of each plate
d = distance between plates
V = p.d. across the plates
q = charge on each plate
$\sigma = charge\ density\ on\ either\ plate = q/A$
Then capacitance of parallel plate capacitor is given by;

$$C = \frac{\epsilon_o A}{d} \quad in\ air$$

$$Capacitance_{parallel\ plate\ capacitor} \propto Area$$

$$Capacitance \propto \frac{1}{d}$$

⇒ If the space between the plates is filled with a medium of absolute permittivity $\epsilon(\epsilon_o K$ *where k is the relative permitivity of the medium*) then capacitance of parallel plate capacitor is given by;

$$C_{medium} = \frac{\epsilon A}{d} = \frac{\epsilon_o K A}{d} \quad in\ a\ medium$$

⇒ As in above equation the capacitance of a capacitor in this case increases k times. So this is the method through which we increase capacitance of a capacitor.

Relative permittivity or dielectric constant:

As;

$$C_{air} = \frac{\epsilon_o A}{d} \quad \rightarrow (i)$$

And;

$$C_{medium} = \frac{\epsilon A}{d} = \frac{\epsilon_o K A}{d} \rightarrow (ii)$$

Dividing equation (ii) by equation (i) we get;

$$K = \frac{C_m}{C_{air}} = \frac{\text{Capacitance of a capacitor with dielectric between the plates}}{\text{Capacitance of the same capacitor with air between the plates}}$$

⇒ So relative permittivity can also be defined as, "The ratio of capacitance of a capacitor having a medium between their plates to the ratio of capacitance of capacitor having air or no medium between their plates".

If someone asked you that the capacitance of a parallel plate air capacitor is measured to be 10μF, and when air is replaced by mica, then the measured value comes to be 20 μF then relative permittivity K or ϵ_r of mica is?

As;

$$\epsilon_r = \frac{C_m}{C_{air}} = \frac{20}{10} = 2$$

Important points:

✓ The relative permittivity of dielectric can be defined in the following ways;

$$\epsilon_r = \frac{\epsilon}{\epsilon_o}$$

$$\epsilon_r = \frac{F_{air}}{F_{medium}}$$

$$\epsilon = \frac{C_{medium}}{C_{air}}$$

✓ For metals k approaches up to *infinity*.

Energy Density between the Plates of a Parallel Plate Capacitor:

⇒ The energy stored in a capacitor is not localized on the charges or the plates but is distributed in the field. And as in case of a parallel plate capacitor field is only between the plates i.e. in a volume (A× d), the so-called energy density.

$$Energy\ density = \frac{Energy}{Volume} = \frac{\frac{1}{2}CV^2}{Ad} = \frac{1}{2}\left|\frac{\epsilon_o A}{d}\right|\frac{V^2}{Ad} = \frac{1}{2}\epsilon_o\left(\frac{V}{d}\right)^2 = \frac{1}{2}\epsilon_o E^2$$

Combinations of capacitor:

⇒ Combination of capacitor means when number of capacitors connected in circuit.

⇒ In such cases we find equivalent capacitor.

⇒ There are two types of combination of capacitor;

i. Series combination

ii. Parallel combination

Series combination	*Parallel combination*
Charge on each plate remains same.	Potential difference across each capacitor same.
Only one path for charge flow.	Many paths for flow of charge.
Equivalent capacitor in this case is given by; $C_{equivalant} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	Equivalent capacitor in this case is given by; $C_{equivalant} = C_1 + C_2 + C_3$
Equivalent capacitance decreases in this case. i.e... $C_{eq} < C_1, C_2, C_3$	Equivalent capacitance increases in this case. i.e.... $C_{eq} > C_1, C_2, C_3$
In series combination potential difference and energy distribution in the reverse ratio of capacitance i.e. $V \propto \frac{1}{C}$ and $U \propto \frac{1}{C}$.	In parallel combination charge and energy distributes in the ratio of capacitance i.e. $V \propto C$ and $U \propto C$.
If two capacitors having capacitances C_1 and C_2 are connected in series then $C_{equivalant} = \frac{C_1 C_2}{C_1 + C_2} = \frac{Multiplication}{Addition}$	If two capacitors having capacitance C_1 and C_2 respectively are connected in parallel then $C_{eq} = C_1 + C_2$; $Q_1 = \left(\frac{C_1}{C_1 + C_2}\right).Q$ and $Q_2 = \left(\frac{C_2}{C_1 + C_2}\right).Q$

$V_1 = (\frac{C_1}{C_1 + C_2}).V$ and $V_2 = (\frac{C_2}{C_1 + C_2}).V$	
If n identical capacitors each having capacitances C are connected in series with supply voltage V then Equivalent capacitance $C_{eq} = \frac{C}{n}$ and Potential difference across each capacitor $V' = \frac{V}{n}$	If n identical capacitors are connected in parallel Equivalent capacitance $C_{eq} = nC$ and Charge on each Capacitor $Q' = \frac{Q}{n}$
Energy stored in series combination of capacitor is; $Total\ energy\ stored = \frac{q^2}{2C_1} + \frac{q^2}{2C_2} + \frac{q^2}{2C_3} + \cdots$ Sum of energy stored in individual capacitor.	Energy stored in parallel combination of capacitor is; $Total\ energy\ stored = \frac{1}{2}C_1V^2 + \frac{1}{2}C_2V^2 \frac{1}{2}C_3V^2 + ..$ Sum of energy stored in individual capacitor.

Important points and Questions for concept:

✓ If several capacitors are first connected in series then in parallel, now you are asked to find ratio of minimum capacitance to maximum capacitance;
As for minimum capacitance the capacitor should be connected in series.
And for maximum capacitance the capacitor should be connected in parallel.
So;

$$\frac{Capacitance_{parallel}}{Capacitance_{series}}$$

✓ The total capacitance of two capacitor is $4\mu F$ when connected in series and $18\mu F$ when connected in parallel. Find the capacitance of each capacitor?
Let C_1 AND C_2 be the unknown capacitance then;

$$C_1 + C_2 = 18 \quad ...(i) \quad when\ in\ parallel$$

$$\frac{C_1C_2}{C_1 + C_2} = 4 \quad ...(ii) \quad when\ in\ series$$

$$Multiplying\ equation\ (i) with\ equation\ , C_1C_2 = 72$$

$$Now;$$

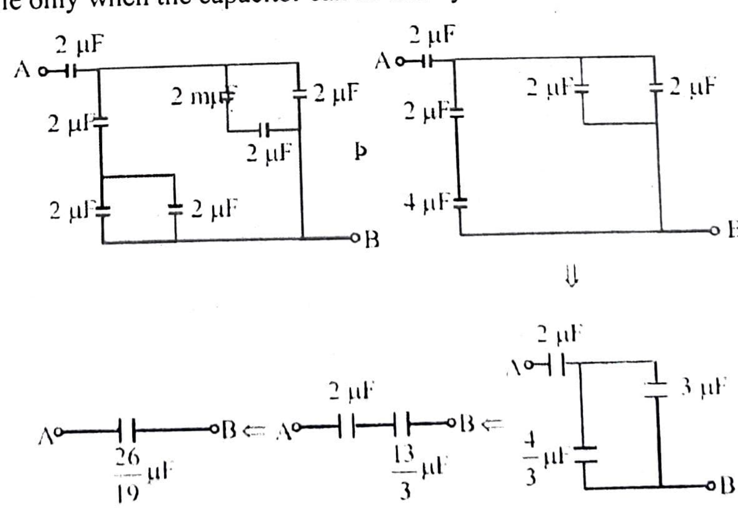
$$C_1 - C_2 = \sqrt{(C_1 + C_2)^2 - 4C_1C_2} = \sqrt{(18)^2 - 4 \times 72} = \pm 6 \quad ...(iii)$$

$$Solving\ equation\ (i) and\ (iii) we\ get\ \ C_1 = 12\mu F\ or\ 6\mu F; \quad and\ C_2 = 6\mu\ or\ 12\mu F$$

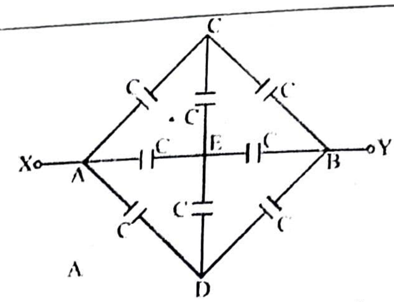
SOME METHODS OF FINDING EQUIVALENT CAPACITANCE

Method1: Successive Reduction

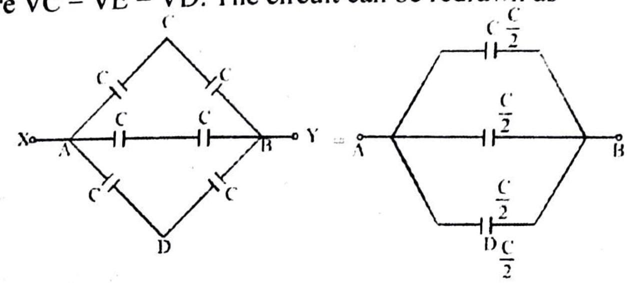
This method is applicable only when the capacitor can be clearly identified as in series or in parallel.

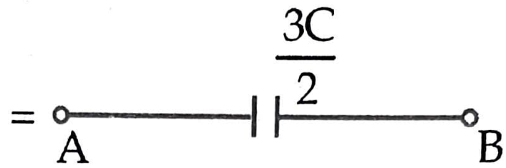


Method 2: Using Symmetry

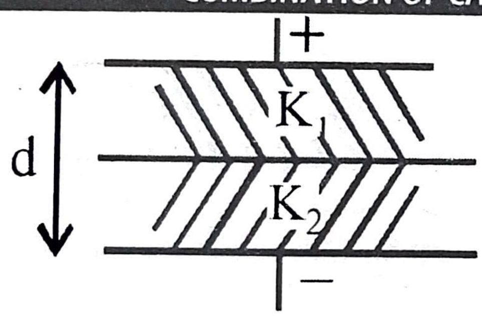


The above circuit is symmetrical about XAEBY axis. This is because the upper part of the circuit is mirror image of lower part. Therefore VC = VE = VD. The circuit can be redrawn as





COMBINATION OF CAPACITOR: EQUIVALENT CAPACITANCE



≡

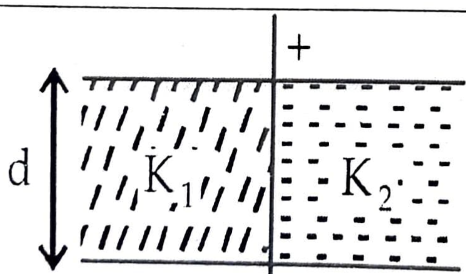


$$C_1 = K_1 \frac{A\varepsilon_0}{d/2}$$

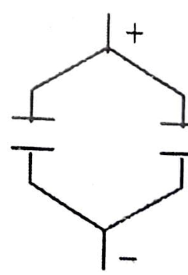
$$C_2 = K_2 \frac{A\varepsilon_0}{d/2}$$

$$d = \frac{d}{2} + \frac{d}{2}$$

And area of each plate A

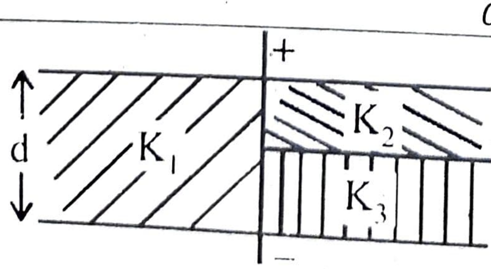


$$\equiv C_1 = \frac{K_1\left(\frac{A}{2}\right)\varepsilon_0}{d}$$

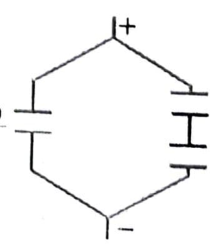


$$C_2 = \frac{K_2\left(\frac{A}{2}\right)\varepsilon_0}{d}$$

$$C_{equivalent} = C_1 + C_2$$



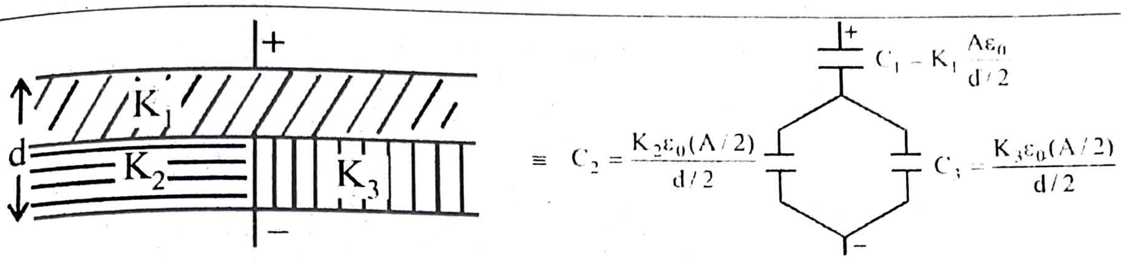
$$\equiv C_1 = \frac{K_1(A/2)\varepsilon_0}{d}$$



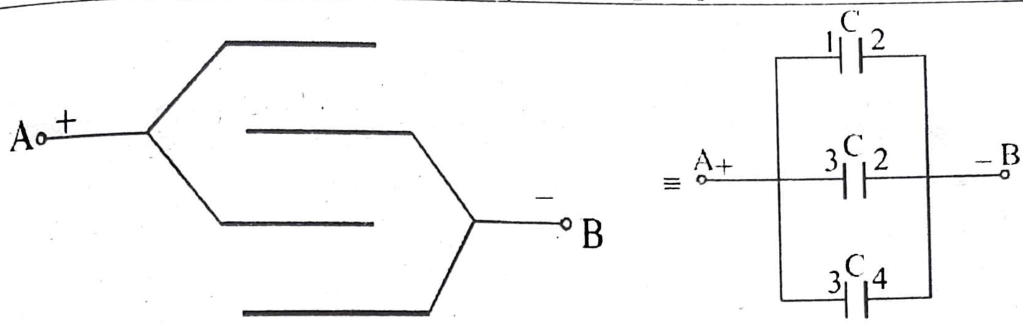
$$C_2 = \frac{K_2(A/2)\varepsilon_0}{d/2}$$

$$C_3 = \frac{K_3(A/2)\varepsilon_0}{d/2}$$

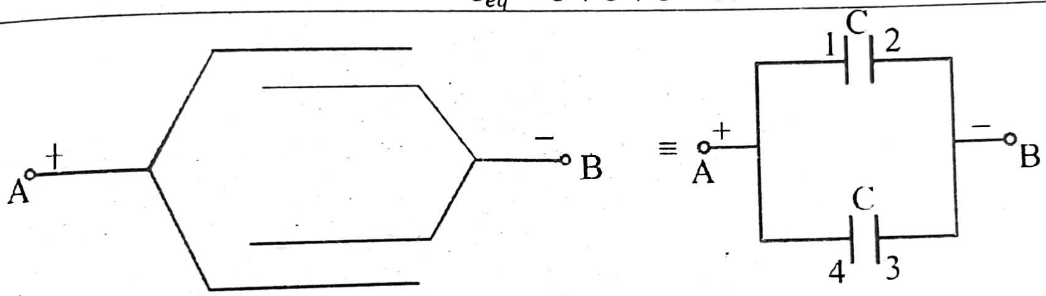
$$C_{equivalent} = C_1 + \frac{C_2C_3}{C_2C_3}$$



$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$



$$C_{eq} = C + C + C = 3C$$



$$C_{eq} = C + C$$

Energy stored in a charged capacitor:

⇒ Charging capacitor means that transferring of electron from one plate to another plate. Therefore, work must have to be done, to move electrons against electric field. This work done is stored in the form of electric potential energy in the electric field between the plates.

⇒ ***Energy stored on the capacitor is given by;***

$U = \frac{1}{2}CV^2$	$U = \frac{1}{2}qV$	$U = \frac{q^2}{2C}$ *joules*

⇒ q is the final charge on capacitor.

⇒ The formula for energy stored is a general expression (we derived it considering capacitor to be of parallel plates) and is applicable to any capacitor.

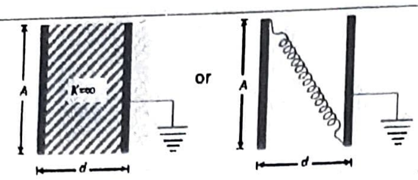
⇒ Note that geometry of capacitor plays no role in energy.

⇒ One important concept is that capacitor stores energy in electric field.

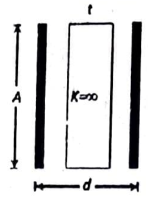
⇒ Then energy supplied by the battery is qV but the energy stored in the capacitor is $\frac{qV}{2}$. the rest half $\frac{qV}{2}$ of energy is wasted in heat in the connecting wire and battery itself.

Question: How we can recover the work done by battery on electrons in capacitor?
Answer: This work is obtained by discharging of capacitor.

When a metallic slab is inserted between the plates:



$C' = \infty$ (*In this case capacitor is said to be short circuited*)



$$Capacitance = C' = \frac{\epsilon_o A}{d - t}$$

Some important discussion:

1) Combination of drops: *Suppose we have n identical drops each having – Radius – r, Capacitance – c, Charge – q, Potential – v and Energy – u.*
If these drops are combined to form a big drop of – Radius – R, Capacitance – C, Charge – Q, Potential– V and Energy – U then –

i. **Charge on big drop:** $Q = nq$

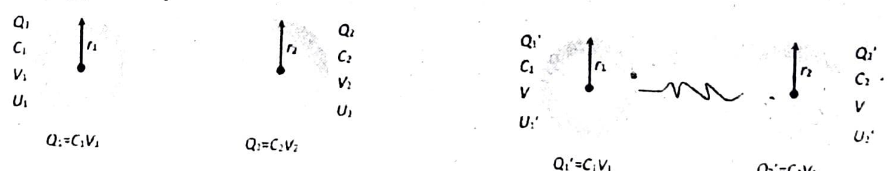
ii. **Radius of big drop:** Volume of big drop = n × volume of a single drop i.e. $\frac{4}{3}\pi R^3 = n \times \frac{4}{3}\pi r^3, R = n^{1/3} r$

iii. **Capacitance of big drop:** $C = n^{1/3} c$

iv. **Potential of big drop:** $V = \frac{Q}{C} = \frac{nq}{n^{1/3} c}$ $\quad V = n^{2/3} v$

v. **Energy of big drop:** $U = \frac{1}{2} CV^2 \Rightarrow \frac{1}{2}\left(n^{\frac{1}{3}} c\right)\left(n^{\frac{2}{3}} v\right)^2$ $\quad U = n^{5/3} u$

2) Sharing of charge: When two conductors joined together through a conducting wire, charge begins to flow from one conductor to another till both have the same potential, due to flow of charge, loss of energy also takes place in the form of heat. Suppose there are two spherical conductors of radii r_1 and r_2, having charge Q_1 *and* Q_2, potential V_1 and V_2 , energies U_1 and U_2 and capacitance C_1 and C_2 respectively, as shown in figure. If these two spheres are connected through a conducting wire, then alteration of charge, potential and energy takes place.



(A) (B)

i. **New charge:** According to the conservation of charge $Q_1 + Q_2 = Q_1' + Q_2' = Q$ *(say)*, also

$$\frac{Q_1'}{Q_2'} = \frac{C_1 V}{C_2 V} = \frac{4\pi\epsilon_o r_1}{4\pi\epsilon_o r_2}, \frac{Q_1'}{Q_2'} = \frac{r_1}{r_2} \Rightarrow 1 + \frac{Q_1'}{Q_2'} = 1 + \frac{r_1}{r_2} \Rightarrow \frac{Q_1' + Q_2'}{Q_2'} = \frac{r_1 + r_2}{r_2}$$

$$\Rightarrow Q_2' = Q\left|\frac{r_2}{r_1 + r_2}\right| \text{ and samilarly } Q_1' = Q\left|\frac{r_1}{r_1 + r_2}\right|$$

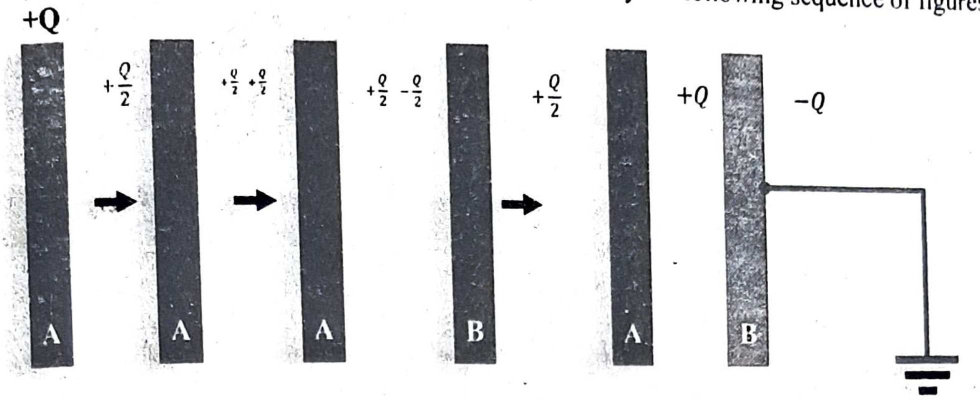
ii. **Common potential:** Common potential $(V) = \frac{Total\ charge}{Total\ capacity} = \frac{Q_1+Q_2}{C_1+C_2} = \frac{Q_1'+Q_2'}{C_1+C_2} = V = \frac{C_1V_1+C_2V_2}{C_1+C_2}$

iii. **Energy loss:** As electrical energy stored in the system before and after connecting the spheres is

$$U_i = \frac{1}{2} C_1 V_1^2 + \frac{1}{2} C_2 V_2^2 \text{ and } U_f = \frac{1}{2}(C_1 + C_2).V^2 = \frac{1}{2}(C_1 + C_2)\left(\frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}\right)^2$$

$$\text{so energy loss } \Delta U = U_i - U_f = \frac{C_1 C_2}{2(C_1 + C_2)}(V_1 - V_2)^2$$

3) Charge on capacitor: Net charge on a capacitor is always zero, but when we speak of the charge Q on a capacitor, we are referring to the magnitude of the charge on each plate. Charge distribution in making of parallel plate capacitor can easily be understand by reading carefully the following sequence of figures –



4) When dielectric is completely filled between plates: If a dielectric slab is filling completely the gap between the plates, capacitance increases by K times i.e., $C' = \frac{k\epsilon_0 A}{d} \Rightarrow C' = kC$

The effect of dielectric on other variables such as charge. Potential difference field and energy associated with a capacitor depends on the fact that whether the charged capacitor is disconnected from the battery or battery is still connected.

Quantity	Battery is removed	Battery Remains connected
Capacitance	$C' = KC$	$C' = KC$
Charge	$Q' = Q(charge\ conserved)$	$Q' = kQ$
Potential	$V' = V/K$	$V' = V\ (battery\ remains\ p.d)$
Intensity	$E' = E/K$	$E' = E$
Energy	$U' = U/K$	$U' = U/K$

5) When separation between the plates is changing: If separation between the plates changes then its capacitance also changes according to $C \propto \frac{1}{d}$ The effect on other variables depends on the fact that whether the charged capacitor is disconnected from the battery or battery is still connected.

1. **Separation is increasing**

Quantity	Battery is removed	Battery is connected
Capacitance	Decreases because $C' \propto \frac{1}{d}$ so $C' < C$	Decreases $C' < C$
Charge	Remains constant because a battery is not present i.e., $Q' = Q$	Decreases because battery is present i.e., $Q' < Q$ Remaining charge $(Q - Q')$ goes back to battery
Potential difference	Increases because $V = \frac{Q}{C} \Rightarrow V \propto \frac{1}{C}$ i.e. $V' > V$	$V' = V$ (Since Battery maintains the potentiai difference)
Electric field	Remains constant because $E = \frac{\sigma}{\epsilon_0} = \frac{Q}{A\epsilon_0}$ i.e. $E' = E$	Decreases because $E = \frac{Q}{A\epsilon_0} \Rightarrow E \propto Q$ i.e. $E' < E$
Energy	Increases because $U = \frac{Q^2}{2C} \Rightarrow U \propto \frac{1}{C}$ i.e. $U' > U$	Decreases because; $U = \frac{1}{2}CV^2 \Rightarrow U \propto C$ i.e. $U' < U$

2. . **Separation is decreasing:**

Quantity	Battery is removed	Battery remains connected
Capacitance	Increases because $C \propto \frac{1}{d}$ i.e.. $C' > C$	Increases $C' > C$
Charge	Remains constant because battery is not present i.e., $Q' = Q$	Increases because battery is present i.e., $Q' > Q$ Remaining charge $(Q' - Q)$ supplied from the battery.

Potential difference	Decreases because $V = \frac{Q}{C} \Rightarrow V \propto \frac{1}{C}$ i.e... $V' < V$	$V' = V$ (Since Battery maintains the potential difference)
Electric field	Remains constant because $E = \frac{\sigma}{\epsilon_o} = \frac{Q}{A\epsilon_o}$ $i.e. E' = E$	Increases because $E = \frac{Q}{A\epsilon_o} \Rightarrow E \propto Q \; i.e. E' > E$
Energy	Decreases because $U = \frac{Q^2}{2C} \Rightarrow U \propto \frac{1}{C}$ $so\ U' < U$	Increases because $U = \frac{1}{2}CV^2 \Rightarrow U \propto C\ so\ U' > U$

Charging and discharging of capacitor:

⇒ When a source supply energy to the capacitor then it is called charging of capacitor.

⇒ When a capacitor supply energy to the source then it is called discharging.

Charging of capacitor:

1. When an uncharged capacitor is connected across a source of constant potential difference such as a cell, it takes a finite time to get fully charged, although this time interval may be small. This time-interval depends on the capacity of the capacitor and the resistance in the circuit
2. During period of charging:
   - ✓ The charge on the capacitor increases from 'zero' to the final steady charge.
   - ✓ The potential difference developed across the capacitor opposes the constant potential difference of the source.
   - ✓ The charge on the capacitor 'grows' only as long as the potential difference of source is greater than the potential difference across the capacitor. This transport of the charge from the source to the capacitor constitutes a transient current in the circuit.
   - ✓ As the charge on the capacitor increases, more energy is stored in the capacitor.
   - ✓ When the capacitor is fully charged, potential difference across the capacitor is equal to the potential difference of the source and the transient current tends to zero.
3. In charging of capacitor there are some terminology like time constant etc. you need to remember this for entrance exams.

i. *Time constant:*

✓ The time duration in which capacitor 63.2% charged or discharged, then this is called time constant.

✓ It is represented by t_c.

✓ Mathematically:

Mathematically time constant is equal to;

$$t_c = RC \quad (R \rightarrow Resistor, C \rightarrow Capacitor)$$

✓ If resistance of resistor is equal to 1 ohm, and capacitance of a capacitor is equal to 1 Farad then the value of time constant is equal to 1 second.

✓ Note that capacitor takes $5t_c$ to completely charging or completely discharging.

$$T = 5t_c$$

$$t_c = \frac{T}{5}$$

$$T = 5R_c$$

✓ Previously we have explained that in 1 t_c capacitor stores 63% of total charge.

✓ So, during 1st t_c the capacitor will store 63% charge (or 63% charged) further charging will occur in remaining 4 t_c. (remaining 37% charging will occur in remaining 4 t_c).

ii. Instantaneous charge stored on each plates of capacitor:

✓ The instantaneous charge stored on each plates of capacitor is given by;

$$Q = Q_o\left(1 - e^{\frac{-t}{RC}}\right)$$

$$Q = instantaneous\ charge\ store$$
$$Q_o = Maximum\ charge\ stored$$
$$t = instantaneous\ time$$
$$RC = time\ constant$$

✓ After 1st time constant, how much charge will be stored?

$$Q = Q_o\left(1 - e^{\frac{-t}{RC}}\right) \; after\ putting\ t = 1t_c\ we\ get;$$

$$Q = 63.2\%Q_o \Rightarrow it\ is\ maximum\ value$$

✓ After 2nd time constant, how much charge will be stored?

$$Q = Q_o\left(1 - e^{\frac{-t}{RC}}\right) \; after\ putting\ t = 2t_c\ we\ get;$$

$$Q = 36.4\%Q_o$$

✓ After 3rd time constant, how much charge will be stored?

$$Q = Q_o\left(1 - e^{\frac{-t}{RC}}\right) \; after\ putting\ t = 3t_c\ we\ get;$$

$$Q = 94\%Q_o$$

✓ After 4th time constant, how much charge will be stored?

$$Q = Q_o\left(1 - e^{\frac{-t}{RC}}\right) \; after\ putting\ t = 4t_c\ we\ get;$$

$$Q = 97\%Q_o$$

✓ After 5th time constant, how much charge will be stored?

$$Q = Q_o\left(1 - e^{\frac{-t}{RC}}\right) \; after\ putting\ t = 5t_c\ we\ get;$$

$$Q = 99.9999999999999999999\%\ Q_o$$

Hence it is clear that

$$Time \propto \frac{1}{ability\ capacitor\ to\ be\ charging\ or\ discharging}$$

iii. Instantaneous potential:

$$V = V_o\left(1 - e^{\frac{-t}{RC}}\right)$$

iv. Instantaneous current:

$$I = I_o\left(1 - e^{-\frac{t}{RC}}\right)$$

Important cases:

✓ At $t = 0, q = 0$.

✓ When t increases, q increases.

✓ $As\ t = \infty, q \to Q_o = CV_o \ \therefore q = Q_o[1 - e^{-\frac{1}{CR}t}$

Discharging of capacitor:

i. If after charging the capacitor, the source of constant potential difference is disconnected and the charged capacitor is shorted through a resistance 'R' then capacitor discharged.

ii. Instantaneous charge remained on each plate:

$$Q = Q_o\, e^{\frac{-t}{RC}}$$

$$Q = instantaneous\ charge\ remained\ on\ each\ plate$$

$$Q_o = maximum\ charge\ stored$$

✓ After 1st time constant, how much charge will be discharged?

$$Q = Q_o\left(e^{\frac{-t}{RC}}\right) \; after\ putting\ t = 1t_c\ we\ get;$$

$$Q = 37\%\ Q_o$$

$$this\ means\ that\ in\ 1\ t_c\ capacitor\ discharged\ 63\%\ and\ 37\%\ charge\ remained$$

✓ After 5th t_c,

$$Q = Q_o\left(e^{\frac{-t}{RC}}\right) \; after\ putting\ t = 5t_c\ we\ get;$$

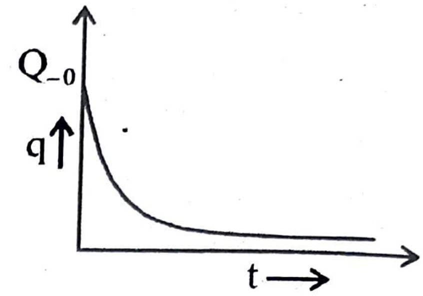
$$Q \cong 0$$

iii. Instantaneous potential during discharging:

$$V = V_o\left(e^{-t/RC}\right)$$

iv. Instantaneous current during discharging:

$$I = I_o(e^{-t/RC})$$



Important cases:

- ✓ the initial condition, $q = Q_0$ $at\ t = 0\ and$
- ✓ the final condition, $q = 0\ at\ t \to \infty$

the solution to the above equation is $q = Q_o e^{-\frac{1}{CR}t}$

FORMULAS SHEET

1.	Coulomb's law	$F_{vac} = \frac{1}{4\pi\epsilon_o}\frac{q_1q_2}{r^2}$	$F_{med} = \frac{1}{4\pi\epsilon_o\epsilon_r}\frac{q_1q_2}{r^2}$	
2.	Electrostatic constant	$k = \frac{1}{4\pi\epsilon_o}$		
3.	Electric intensity	$E = \frac{F}{q}$	$\vec{E} = \frac{\vec{F}}{q_{test}}$	$F = qE$
4.	Electric intensity due to a point charge	$E = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2}$	$\vec{E} = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2}\hat{r}$	$E = \frac{kq}{r^2}$
5.	Electric flux	$\phi = \vec{E}.\vec{A}$	$\phi = EA\cos\theta$	$E = \frac{\phi}{A}$
6.	Electric fiux through closed surface	$\phi = \frac{q}{\epsilon_o}$		
7.	Gauss's law for electrostatics	$\phi = \frac{1}{\epsilon_o} \times (Q)$	$\phi = \frac{Q}{\epsilon_o}$	
8.	Surface charge density	$\sigma = \frac{q}{A}$		
9.	Electric field intensity inside a hollow conducting sphere	$E = 0$		
10.	Electric intensity due to infinite sheet of charge	$E = \frac{\sigma}{2\epsilon_o}$	$\vec{E} = \frac{\sigma}{2\epsilon_o}\hat{r}$	
11.	Electric field intensity between two oppositely charged plates	$E = \frac{\sigma}{\epsilon_o}$	$\vec{E} = \frac{\sigma}{\epsilon_o}\hat{r}$	
12.	Electric potential difference	$\Delta V = \frac{W}{q}$	$\Delta V = \frac{\Delta U}{q}$	
13.	Relationship between electric potential energy and electric potential difference	$\Delta U = q\Delta V$	$V = \frac{U}{q}$	$U = qV$
14.	Relationship between electric intensity and electric potential difference (Potential gradient)	$E = -\frac{\Delta V}{\Delta r}$	$V = Ed$	
15.	Absolute electric potential difference	$V = \frac{W}{q}$		
16.	Capacitance of capacitor	$q = CV$	$C = \frac{q}{V}$	
17.	Capacitance of parallel plate capacitor	$C_{vac} = \frac{A\epsilon_o}{d}$	$C_{med} = \frac{A\epsilon_o\epsilon_r}{d}$	
18.	Dielectric constant	$\epsilon_r = \frac{C_{med}}{C_{vac}}$	$\epsilon_r = \frac{\epsilon_{med}}{\epsilon_{vac}}$	$\epsilon_r = \frac{F_{vac}}{F_{med}}$
19.	Energy stored in a capacitor	$E = \frac{1}{2}qV$	$E = \frac{1}{2}CV^2$	$E = \frac{1}{2}\frac{q^2}{C}$
20.	Energy density of electric field	$\rho_{electric} = \frac{1}{2}\epsilon_o\epsilon_r E^2$		
21.	RC- Time constant	$t = RC$		
22.	Charging of capacitor			
23.	Discharging of capacitor			

UNITS

1.	Electrostatic constant (k)	Nm^2C^2	
2.	Permittivity of free space	$C^2N^{-1}m^{-2}$	
3.	Relative permittivity	*no unit*	
4.	Electric intensity	N/C	V/m

5.	Electric flux	Nm^2C^{-1}	
6.	Surface charge density	C/m^2	
7.	Electric potential difference	J/C	$Volt$
8.	Electrical energy	eV	
9.	Capacitance	C/V	$farad$
10.	Dielectric constant	$No\ unit$	
11.	Energy density	J/m^3	
12.	RC-time constant	$second$	

CONSTANTS

1.	Electrostatic constant	$9\times10^9\ Nm^2C^{-2}$
2.	Permittivity of free space	$8.85\times10^{12}N^{-1}m^{-2}C^2$
3.	Relative permittivity of air	1.0006
4.	Relative permittivity of free space	1
5.	Charge on electron	$1.6\times10^{19}C$

Some important Points

1) The electric charge exists on material bodies which occupy space. Hence electric charge is not a point.
2) The quantization effect of charge can be observed only at microscopic level.
3) The charge can be created or destroyed in equal and unlike pairs only.
   Examples: pair production, pair annihilation.
4) The electric charge always resides on the outer surface of the charged conductor.
5) Coulomb s law is valid only for stationary point charges and for particle separation ranging from 10^{-15} m and above.
6) Two charges Q are at distance r from each other If third charge q(= - Q/4) is placed at a distance of (r/2) from each charge, then system Of charges will be in equilibrium.
7) At the microscopic level, charge distribution is discontinuous.
8) Conceptually, continuous charge distribution is analogous to the continuous mass distribution in mechanics.
9) For a surface charge distribution, electric field is discontinuous across surface.
10) For a volume charge distribution, electric field is defined at any point in distribution.
11) The electric field, as per theory, extends up to infinity.
12) A charge does not experience any force due to its own electric field.
13) If the electric lines of force are parallel and equally spaced, the field is uniform.
14) If E_0 and E be the electric field intensity at a point due to a point charge or a charge distribution in vacuum and in medium of dielectric constant K then $E = KE_o$
15) If test charge has significant value, it will change, value of electric field to be measured.
16) For $+q, \vec{F}$ and $\vec{E}$ are in same direction i.e., perpendicular to surface directing outwards.
17) For $-q, \vec{F}$ and $\vec{E}$ are in opposite direction and $\vec{E}$ is perpendicular to surface directing inwards.
18) At neutral point $\vec{E} = 0$.
19) If electric field intensity' is same both in magnitude and direction throughout then electric field is said to be uniform. Uniform electric field is represented by equispaced parallel lines.
20) At all points other than those on axial and equatorial lines, the field will curve towards or Away from the charges.
21) The value of electric flux is independent of the distribution of charges and the separation between them inside the closed surface.
22) Gaussian surface cannot pass through any discrete charge.
23) If wire is not infinitely long, the end effects need to be considered.
24) For a finite sheet, edge effects need to be considered.
25) Potential due to a point charge q at its own location is not defined.
26) Value of V is same at all points at equal distances from a point charge. Hence potential due to a single charge is said to be spherically symmetric.

27) The maximum electric field that a dielectric medium can withstand, without breaking down of its insulating property is called its dielectric strength.
28) The capacity of conductor depends on its shape and size, presence of other charged conductor placed nearly and nature of surrounding medium.
29) As the potential of the earth is assumed to be zero, capacity' of conductor connected to earth (whatever its shape or charge on it) will be infinite.
30) A capacitor allows ac but blocks dc.
31) Even if the current through capacitor is zero, a finite amount of energy can be stored in a capacitor.
32) If space between the plates is completely filled with a conductor then. $k = \infty$ *and hence* $C = \infty$.
33) Series combination is useful, when a single capacitor is not able to tolerate a high potential drop. So it is distributed among number of capacitors.
34) Parallel combination is useful when high capacity is required at low potential.
35) Capacitor actually stores electric energy in the form of electric field between the plates.
36) The net charge on the capacitor is zero.
37) The potential energy stored in the capacitor is independent of the manner in which charge configuration of the capacitor is built up.
38) The potential energy of capacitor lies in the dielectric medium between the plates.
39) The potential energy of capacitor is obtained at the cost of chemical energy stored in the battery used for charging the capacitor.

Tips and Tricks

1) If magnitude of a charge is given and you are asked "is this charge is possible?" like a question is asked that, is the charge of $4.5 \times 10^{-19}C$ exists?

First check through equation; $q = ne \Rightarrow n = \frac{q}{e} \Rightarrow \frac{4.5\times10^{-19}}{1.6\times10^{-19}} \Rightarrow 2.8$

Like here n is not integer so this value of charge is not possible.

Important tip is;

As we know that smallest charge in universe is $1.6 \times 10^{-19}C$ so the charge must not be less than $1.6 \times 10^{-19}C$.

✓ If charge given is smaller than $1.6 \times 10^{-19}C$ then it is impossible. Directly click your option without going to calculation.

✓ If charge given is greater in magnitude ($Charge\ is\ greater\ than\ 1.6 \times 10^{-19}C$) then see it through equation $n = q/e$.

2) $Charge\ on\ a\ body \geq 1.6 \times 10^{-19}C$

3) If you are given two objects, and someone say that 'A' is rubbed with 'B' in this case 'B' acquires charge of $+4.5 \times 10^{-19}C$ from 'A';

✓ Now the charge on 'A' will be $-4.5 \times 10^{-19}C$.

✓ The no of electron lost by object 'B' is; $n = \frac{q}{e} \Rightarrow \frac{4.5\times10^{-19}C}{1.6\times10^{-19}C}$

✓ *Mass transfer from B to A;*

$$Mass\ transfer = n \times (9 \times 10^{-31})$$
$$n = no\ of\ electrons$$
$$9 \times 10^{-31} = Mass\ of\ electron$$

4) If a body gives out n electrons to another body every second, how much time is required to get a total charge of n coulomb from it?

$$Charge\ given\ per\ second = q = ne$$
$$if\ t\ is\ time\ rerquired\ then, Q = qt \Rightarrow t = \frac{Q}{q}$$
$$Q = total\ charge\ of\ n\ coulomb\ gain\ from\ n\ electrons$$
$$q = Charge\ given\ per\ second$$

The answer of t will be your required answer.

- ✓ If you are asked in years, minutes, days or hours then convert your answer from seconds to these conversions.

5) If we have two small spheres of same size.
Charge given to sphere 1st is = $+20\mu C$
Charge given to sphere 2nd is = $-5\mu C$
After that they are allowed to touch each other and then separated by 10 *cm*, Assuming air as medium the force exists between them is?

$$After\ touching\ each\ other\ resultant\ charge = (20) + (-5) = 15\mu C$$

$$Now\ after\ separation\ chaarge\ on\ each\ sphere, q_1 = q_2 = \frac{15}{2} = 7.5\mu C$$

$$F = 9\times10^9\frac{q_1q_2}{r^2} \Rightarrow 9\times10^9\frac{(7.5\times10^{-6})(7.5\times10^{-6})}{(0.1)^2} = 50.62N$$

The force will be Repulsive.

6) Three charges each of $1\mu C$ are placed at the corner of equilateral triangle. If the force between any of two charges be 'F' the net force on each charge will be,
So, on any charge 2 equal force each of magnitude F acts then angle between them will be 60°. So;

$$R = \sqrt{F^2 + F^2 + 2FFcos60°} = \sqrt{F^2 + F^2 + F^2} = \sqrt{3}F$$

7) If mass, 'm' and 'E' is given and you are asked to find charge then put these values in the following equation;

$$q = mg/E$$

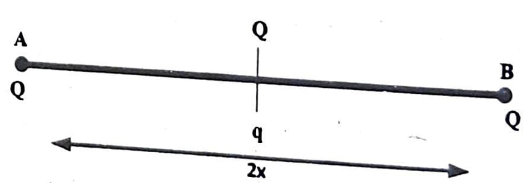
8) If particle of mass 'm' and charge 'q' is thrown at a speed of v_o m/s against a uniform electric field 'E'. How much distance 'S' will it travel before coming to rest momentarily;

$$First\ find\ acceleration; a = -\frac{F}{m}$$

$$then\ find\ distance; s = \frac{v^2 - v_o^2}{2a}\quad value\ of\ v^2\ is\ taken\ as\ zero\ and\ value\ of\ v_o^2\ will\ be\ given$$

9) If two charges are of same sign (Both positive or both negative) the point of zero resultant will lie between them or their center.

10) A charge q is placed at the center of the line joining two charges (each of magnitude Q) then on which condition the charges will be on equilibrium?
They might give you options like;
(a) $q = Q/4$
(b) $q = -Q/4$
(c) $q = 3Q/4$
(d) $q = 4Q/3$



$$As\ AD = BD = X$$

So, for equilibrium the net force on each charge must be zero;
So;

$$\frac{1}{4\pi\epsilon_o}\frac{Qq}{x^2} + \frac{1}{4\pi\epsilon_o}\frac{QQ}{(2x)^2} = 0$$

$$\frac{Qq}{x^2} + \frac{Q^2}{4x^2} = 0$$

$$\frac{Qq}{x^2} = \frac{-Q^2}{4x^2}$$

$$q = -\frac{Q}{4}$$

11) As Coulomb's force and gravitational force both have inverse dependent of r.
The strength of these 2 forces;

- ✓ *For electron and proton;*

$$|F_e| = \frac{1}{4\pi\epsilon_o}\frac{e\times e}{r^2}\qquad |F_g| = \frac{Gm_em_p}{r^2}$$

The ratio

$$\frac{|F_e|}{|F_G|} = \frac{1}{4\pi\epsilon_o} \times \frac{e^2}{Gm_e m_p} \Rightarrow 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{6.67 \times 10^{-11} \times 9.11 \times 10^{-31} \times 1.67 \times 10^{-27}}$$
$$= 2.4 \times 10^{39}$$

✓ *For two protons:*

$$\frac{|F_e|}{|F_G|} = \frac{1}{4\pi\epsilon_o} \times \frac{e^2}{Gm_p m_p} \Rightarrow 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2} = 1.3 \times 10^{36}$$

12) ***Force of attraction between electron and proton is;***

$$F = \frac{1}{4\pi\epsilon_o}\frac{e^2}{r^2} \Rightarrow 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{(1 \times 10^{-10})^2} = 2.3 \times 10^{-8} N$$

13) ***Acceleration of electron:***

$$AS\ F = ma \Rightarrow a = \frac{F}{m} = \frac{2.3 \times 10^{-8}}{9.11 \times 10^{-31}} = 2.5 \times 10^{22} m/s^2$$

14) ***Acceleration of proton:***

$$AS\ F = ma \Rightarrow a = \frac{F}{m} = \frac{2.3 \times 10^{-8}}{1.67 \times 10^{-27}} = 1.4 \times 10^{19}\ m/s^2$$

15) Electrostatic experiment cannot be successfully conducted on humid days, because the humid air become conducting.
16) Attraction exist between charged body and uncharged body as well as between bodies having opposite charges.
17) Repulsion will only takes place between body having similar charges.
18) Earth is a very big source of electron or sink so any object connected to earth is said to be grounded.
19) Two balls having the same kind of charges may attract each other, this is true because if charge on one ball is greater as compared to the charge on other. They will attract each other because a ball of large charge will induced oppositely large charge on another ball in this way they will attract each other.
20) Proton cannot be removed from the body.
21) A soap bubble or rubber balloon expands on given charge to it (charge of any kind + or –).
22) Benjamin Franklin was the first to assign positive and negative sign of charge.
23) The existence of two type of charges was discovered by Dufog.
24) Franklin (i.e., e.s.u. of charge) is the smallest unit of charge while faraday is largest (1 Faraday = 96500 C
25) Charge cannot exist without mass though mass can exist without charge.
26) A charge is said to be in equilibrium, if net force acting on it is zero. A system of charges is said to be in equilibrium if each charge is separately in equilibrium.
27) A charged particle at rest produces only electric field in the space surrounding it. However, if the charged particle is in unaccelerated motion it produces both electric and magnetic fields. And if the motion of charged particle is accelerated it not only produces electric and magnetic fields but also radiates energy in the space surrounding the charge in the form of electromagnetic waves.
28) Quantization of charge implies that there is a maximum permissible magnitude of charge.
29) After earthing a positively charged conductor electrons flow from earth to conductor and if a negatively charged conductor is earthed then electrons flows from conductor to earth.
30) Lightening-rods arrestors are made up of conductors with one of their ends earthed while the other sharp, and protects a building from lightening either by neutralizing or conducting the charge of the cloud to the ground.
31) With rise in temperature dielectric constant of liquid decreases.
32) Induction takes place only in bodies (either conducting or non-conducting) and not in particles.
33) If only one charge is available than by repeating the induction process, it can be used to obtain a charge many times greater than its equilibrium. (High voltage generator).
34) Coulombs law is not valid for moving charges because moving charges produces magnetic field also.
35) Coulombs law is valid at a distance greater than $10^{-15}m$.
36) Decreasing order to fundamental forces $F_{Nuclear} > F_{electromagnetic} > F_{week} > F_{Gravitational}$.
37) Two-point charges separated by a distance r in vacuum and a force F acting between them. After filling a dielectric medium having dielectric constant K completely between the charges, force between them

decreases. To maintain the force as before separation between them changes to r K . This distance known as effective air separation

38) No point charge produces electric field at its own position.
39) A small ball is suspended in a uniform electric field with the help of an insulated thread. If a high energy x-ray bean falls on the ball, x-rays knock out electrons from the ball so the ball is positively charged and therefore the ball is deflected in the direction of electric field.
40) Electric field is always directed from higher potential to lower potential.
41) A positive charge if left free in electric field always moves from higher potential to lower potential while a negative charge moves from lower potential to higher potential.
42) The practical zero of electric potential is taken as the potential of earth and theoretical zero is taken at infinity.
43) An electric potential exists at a point in a region where the electric field is zero and it's vice versa.
44) It is a common misconception that the path traced by a positive test charge is a field line but actually the path traced by a unit positive test charge represents a field full line only when it moves along a straight line.
45) Capacity of a conductor is a constant term, it does not depend upon the charge Q, and potential (V) and nature of the material of the conductor.
46) It is a very common misconception that a capacitor stores charge but actually a capacitor stores electric energy in the electrostatic field between the plates.
47) Two plates of unequal area can also form a capacitor because effective overlapping area is considered.
48) If two plates are placed side by side then three capacitors are formed. One between distant earthed bodies and the first face of the first plate, the second between the two plates and the third between the second face of the second plate and distant earthed objects. However, the capacitances of the first and third capacitors are negligibly small in comparison to that between the plates which is the main capacitance.
49) Capacitance of a parallel plate capacitor depends upon the effective overlapping area of plates $C \propto A$ separation between the plates $C \propto \frac{1}{d}$ and dielectric medium filled between the plates. While it is independent of charge given, potential raised or nature of metals and thickness of plates.
50) The distance between the plates is kept small to avoid fringing or edge effect (non-uniformity of the field) at the boundaries of the plates.
51) Spherical conductor is equivalent to a spherical capacitor with its outer sphere of infinite radius.
52) A spherical capacitor behaves as a parallel plate capacitor if its spherical surfaces have large radii and are close to each other.
53) The intensity of electric field between the plates of a parallel plate capacitor ($E = \sigma/\epsilon_o$) does not depends upon the distance between them.
54) The plates of a parallel plate capacitor are being moved away with some velocity. If the plate separation at any instant of time is 'd' then the rate of change of capacitance with time is proportional to $1/d^2$.
55) Radial and non-uniform electric field exists between the spherical surfaces of spherical capacitor.
56) When two identical conductors having charges q1 and q2 are kept in contact and separated later then each has charge of $\left(\frac{q_1+q_2}{2}\right)$.
57) If charges are q1 and - q2, then, each has charge $\left(\frac{q_1-q_2}{2}\right)$.
58) Coulomb's law is in accordance with the Newton's third law of motion. $\vec{F}_{q1q2} = -\vec{F}_{q2q1}$
59) It two charges q1 and q2 are separated by distance r, then distance x between charge q, and null point

$$x = \frac{r}{\sqrt{\frac{q_2}{q_1}} - 1}$$

60) By introducing dielectric slab between plates of charged capacitor, capacitance increases, potential difference decreases and charge remains unchanged.
61) If n plates are arranged be, then they constitute (n— 1) capacitors in parallel. The resultant capacitance of this combination is given by;

$$C = (n-1)\frac{\varepsilon_o A}{d}$$